Experiences of linking 2 European LCI databases and 3 LCIA methods for land use impacts

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Contents:
1 Previous experiences and present project
2 Experiences with the ETH 1996 database
3 Combining 3 impact assessment methods for land use
4 Data sources
5 Conclusions

1 Previous experiences and present project

The main commissioner for LCA land use projects in the Netherlands is the Dutch Ministry of Transport, Public Works and Water Management (division DWW). They are concerned about questions regarding mineral planning policy, including:

- the choice for new sand pits on land or sand extraction from sea,
- the preference for bricks, made from abundantly available clay, over concrete, made from scarce resources, and
- the use of different kinds of woods in builing and construction to replace mineral raw materials.

Since 1995 this ministry has commissioned two methodological studies to IVAM Environmental Research (University of Amsterdam). This resulted in a method with globally applicable indicators for biodiversity and life support impacts of land use [Lindeijer, 1998], [Lindeijer, 2000]. In this project a clear distinction was made between occupation (expressed in m2.y) and transformation (expressed in m2)[1] within land use impacts.

In the project on Eco-Quantum (an LCA-based designers tool for buildings) occupation data was collected, compared with those of the ETH 1994 database[2] [Frischknecht, 1994] and implemented in the IVAM LCA database [Mak, 1996]. There were large discrepanties between the Dutch and Swiss data. The ETH data was generally up to orders of magnitude higher. The format used was based on the specific indicators developed for the Ministry.

Presently, a project is run for the same Ministry, with additional funding from a research organisation called Delft Cluster [Lindeijer et al., 2001]. The first phase of the project deals with land use methodology and data collection for the building sector. Regarding methodology, a combination is made of the IVAM method [Lindeijer et al., 1998] and the method proposed in the LCAGAPS project [Weidema & Lindeijer, 2001], using data presentation according to [Köllner, 2001]. Also, the ETH 1996 database is analysed regarding land use, in order to improve its land use data presentation. For aggregates, Dutch extraction land use data and biodiversity data is collected. For wood, relevant global land use and biodiversity data is collected. Also, the data collected in the Eco-Quantum project is improved. The second phase of the project deals with desiccation, and is not discussed further here.

2 Experiences with the ETH 1996 database and IVAM ER database

In the ETH database up till now, land occupation and land transformation has been mixed in one terminology. A name like III-IV included the change from category III to category IV, occupation as category IV and recovery to category III. This is unwanted, as transformation gives a different kind of information: on the trend in land

[1] In the ETH database up till now, the only unit used was m2.y (now used for occupying a certain area during a certain time), and the terminology used was that of transformations from one land use category to another. In this project, both were separated. Transformation is additional information to occupation, and depicts *only* the net change between the situation before and after the activity, irrespective of the occupation time. Therefore the unit is just m2. When an activity results in the same quality as before, transformation is zero. Occupation is about all area used during a certain time, which may include area under renaturation (recovery to a more natural state).
[2] Although this Swiss LCA database is developed with various partners, the database in all its development stages is simply called the ETH database here.

use[3]. Also, documentation was often incomplete and sometimes lacking. This has hampered a thorough analysis of the land use data in the ETH database. The first attempt to do so was performed in 1996, using the 1994 database. In the 1996 database, more land use information on infrastructure was added.

In the present Delft Cluster project, we again analysed the ETH land use data. Infrastructure appeared dominant for some types of electricity production and land use, whereas some land use types were dominated by only a few processes. Some examples are given below.

Land use category contribution of infrastructure for electricity from gas (UCPTE):

- Category II-III 53%
- Category IV-IV 60%
- Category II-IV 65%
- Category III-IV 100%

Process contribution to EcoInventar category II-III for electricity from coal:

- Steinkohle aus Tagbau ab Bergwerk 52%
- Steinkohle aus Untertagebau ab Bergwerk 12%
- Infra Steinkohle Untertagebau ab Bergwerk 3%
- Infra Schiene 2%

The dominance analysis is performed by linearisation of the matrix-based database via a kind of Monte Carlo optimalisation, and importing the results in the linear SIMAPRO software in a few levels of aggregation. The original matrix software was no longer available to perform this analysis quicker.

After this dominance analysis the dominant processes have been studied to determine the actual information available for occupation and transformation in the ETH database documentation [Frischknecht, 1994], [Frischknecht, 1996]. Then the format of the dominant processes could be changed into the occupation and transformation format required for the Delft Cluster project. Finally, a set of major ETH database outputs adapted to the Dutch situation and agreed to be used in the Dutch building sector [Eggels & van der Ven, 2000] have to be recalculated using the same Monte Carlo procedure as for the dominance analysis. By this means a consistent set of land use data is provided for use in ‘background processes’ in the building sector.

3 Combining 3 impact assessment (IA) methods for land use

Data constraints still limit the possibilities and steer choices in the development of land use impact assessment methods for land use. Below, some characteristics of 3 recent land use IA methods are mentioned [Lindeijer et al, 1998], [Weidema & Lindeijer, 2001] and [Köllner, 2000]. These have determined our choices in how to combine these methods into one approach [Lindeijer et al., 2001].

Table 3.1 Overview of some characteristics of 3 land use methods

Characteristic	Applied in method(s)
Vascular plant species diversity as an indicator for biodiversity impacts	Lindeijer et al., 1998 Weidema & Lindeijer, 2001 Köllner, 2000
Case scores for original species	Weidema & Lindeijer, 2001
Case scores for threatened species	Köllner, 2000
Case scores for all species	Lindeijer et al., 1998 Köllner, 2000
Relate to reference state: relative to the maximum score in a region	Lindeijer et al., 1998 Weidema & Lindeijer, 2001
Relate to reference state: relative to the average in a region	Köllner, 2000
Globally differentiated reference state	Lindeijer et al.., 1998 Weidema & Lindeijer, 2001
Including factors on ecosystem level (scarcity and vulnerability)	Weidema & Lindeijer, 2001
Using Fischer formula for standardising biodiversity data	Lindeijer et al., 1998
Using Arrhenius formula for standardising biodiversity data	Köllner, 2000

[3] Information on trends is seldom included in LCA’s (being basically a static tool), but is especially important for land use. The loss of nature value through land transformations is ever increasing world wide, and dominates for instance biodiversity impacts of man [Sala, 2000].

Biomass as an indicator for life support impacts	Lindeijer et al.., 1998 Weidema & Lindeijer, 2001

Combining the best of these methods, we developed the following formulas for physical land use impacts in LCA, consisting of two ecosystem factors and one species density factor:

EO (Ecosystem Occupation) $= A \times t \times ES^i \times EV^i \times SD$
ET (Ecosystem Transformation) $= A \times ES^i \times EV^i \times (S_{ini}{}^{stand} – S_{fin}{}^{stand}) / S_{ref}{}^{stand}$
BL (Biomass for Life support) $= A \times fNPP$ or $A \times NPP$

where
- A = occupied area
- t = occupation time
- SD = $(1 – S_{act}{}^{stand} / S_{ref}{}^{stand})$ $(0 \leq SD \leq 1)$
- ES^i = ecosystem scarcity of biome i = $A_{pot,max} / A_{pot,\,i}$ $(ES \geq 1)$
- EV^i = ecosystem vulnerability of biome i = $(A_{exi}/A_{pot})^{b-1}$ $(EV \geq 1)$
- $A_{pot,i}$ = area of biome i
- A_{exi} = actual area of biome i
- A_{pot} = potential area of biome i
- b = species accumulation factor (fitting parameter; set to 0,2)
- $S_{act}{}^{stand}$ = species density per 0,01 ha during occupation
- $S_{ref}{}^{stand}$ = species density per 0,01 ha of the reference state
- S_{ini} = initial species density per 0,01 ha
- S_{fin} = final species density per 0,01 ha
- NPP = net primary production of biomass in kg C per m2 per year
- fNPP = free net primary production (NPP minus what is harvested by man)

Compared to the formula from IVAM ER [Lindeijer et al., 1998] the species density is no longer expressed as _, but in the same terms as [Köllner, 2000], and the two ecosystem factors from [Weidema & Lindeijer, 2001] are added.

The two major remaining value choices where no clear choice could be made were:
- the average or the maximum species density as reference state
- using NPP or fNPP as an indicator for substance/energy cycles and topsoil quality

Both choices relate to an anthropocentric (individualist?) or a biocentric (egalitarian?) viewpoint, respectively. As these choices are still open, we strive to express both.

4 Data sources

For the above method, various data (inventory and impact assessment) need to be collected. It has proven a very difficult task to do so for all processes in an LCA, as such data is not readily available in databases. Below is outlined how this task is performed in the Delft Cluster project.

Inventory data
Next to the background data in the ETH database, land use data for foreground processes in the Dutch building sector need to be included. This was performed as follows:

Aggregate extraction:	A governmental CDROM data on over 400 locations was analysed, resulting in about 40 sets of useful data. Fairly significant results for transformation were found. For occupation the total extraction time was lacking, and additional data sources were required.
Metals mining:	Specific data sources for aluminium and copper are used; for others we resort to the ETH database or estimates.
Wood extraction:	The FAO Forest Resource Assessment 2000 is used, looking at forest area or area under harvesting scheme for land use and volume harvested for the functional unit, for countries from which wood is imported in the Netherlands.
Industrial production:	National statistics on land use (occupation and changes to and from industry) and industrial production were applied, filling in gaps with a factor on the production in kg per guilder output for known sub-sectors.
Transport:	Direct land use via Dutch national statistics on area occupied and changed; allocation to goods transport based on yearly vehicle km.

Living: National statistics on land occupation and changes are used to determine the occupation and transformation due to dwellings.
Waste disposal: For incineration, a specific Dutch case is taken and compared to the ETH data. For waste disposal the same is done.

For the reference state, no inventory data is required. For normalisation national and EU statistics on land use are used. Occupation data easily result from interpreting the land cover in terms of the land use types from [Köllner, 2000]. Transformation data result from the CORINE database.

Preliminary cases are chosen (inner and outer walls), where bricks, concrete and wood are main alternatives. These cases have not yet been calculated, as all land use data have to be inserted in a database first.

Impact assessment data
For the species density factor in the biodiversity indicator, we use data from [Köllner, 2000] for most cases. In order to be consistent, we have to use the same standardisation area (0,01 ha) and –formula (the Arrhenius formula with parameters a = 4,1 and b = 0,2) for the reference state. By fitting the various data sources we could argue that this is an acceptable procedure, giving reasonable results. For Dutch cases we tried to use a Dutch database on biodiversity data. This has not yet succeeded up to date.

For the ecosystem factor, we had to adapt the original b = 0,15 to 0,2 in the ecosystem vulnerabilty formula from [Weidema & Lindeijer, 2001]. Data on the actual and potential area were taken from the IMAGE 2.1 model [Leemans et al., 1998] used by the Dutch RIVM for presenting global warming scenarios. The choice for this model was made in [Weidema & Lindeijer, 2001], out of several USGS and other models. The consistency of actual and potential biome area was crucial in this choice, as these data dominate the total land use score with ranges a factor 10 higher than those of species diversity.

For the biomass indicator, som case data is available from [Weidema & Lindeijer, 2001] and from [Lindeijer et al., 1998]. It can also easily be calculated for agriculture and silviculture products using growth and harvesting statistics or specific case data. Reference data is taken from [Leemans et al., 1998].

5 Conclusions

Collecting land use inventory data is a time consuming job, and virtually impossible for a single LCA life cycle. It is therefore required that adequate land use data is included in all major databases, if land use is to be included in LCA's at all. Adequate means that at least regional differentiation is included[4], for instance by stating the country code, for instance as follows:

occupation ([type], [further specification], [country code according to ISO])
transformation ([type initial], [further specification]>[type final], [further specification], [country code])

This proposal matches the SETAC WIA document on Impact Assessment. We suggest to use the terms occupation and transformation only (instead of using the prefix 'land area'), as the units show that land area is meant.

Also, at least about 20 of the different land use types from [Köllner, 2000] should be distinguished. For the core of the ECOINVENT database, probably less different land use names could do. One could even resort to the simple 5 categories (including benthos), and add only the most relevant transformations. With the regional differentiation, this would still result in about 20 different items.

The above requirements implies the importance of including land use transparently in the ECOINVENT 2000 database. Then, land use can be included in all LCA studies using the ECOINVENT database.

Including transformation implies including a new kind of information in LCA's: the contribution of a case to the trend in the 'background level'. This is especially relevant for land use, where a relatively large part of the natural background is intervened by humans and changes still occur at a high speed. In interpreting land use impacts, this information will be as important as the contribution to the impacts of the total area occupied. One could state that transformation expresses the trend in not-reversed land cover changes.

[4] For the IVAM ER formula [Lindeijer et al., 1998] it was calculated that a factor of an order of magnitude extra mistake is made when regional differentiatiojn is not included. For the new TNO formula the mistake will even be bigger due to the larger range in ecosystem factors.

Developing an impact assessment method for land use implies many choices, of which some can not be solved by the researcher and have to be presented to the user, including a proposed interpretation. Major data ranges due to natural variations and definitions of categories will anyhow result in large uncertainty ranges. This implies that land use impacts will be assessed within a range of an order of magnitude. Land use impact scores will remain indicative for possible problems and discussion points. The LCA user should be aware of this, and help the public or commissioner to interprete the results and to open discussions related to valuing land use.

It is an open question whether still further development of the land use impact assessment method is required. We do need to develop land use impact assessment practice. Therefore, it seems important that the inventory data catches up with the IA developments of the last few years. If not, application of these methods will be seriously hampered.

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